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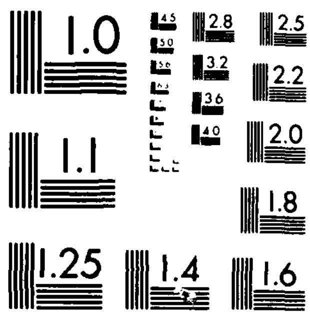
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SOME EFFECTS OF SMOKING WITHDRAWAL ON COMPLEX PERFORMANCE AND PHYSIOLOGICAL RESPONSES

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16. Abstract

The effects of smoking withdrawal on complex (time-shared) performance and physiological responses were studied at a simulated aircraft cabin altitude of 6,500 ft. Seventeen habitual smokers, nine women and eight men 23 to 59 years of age, served as subjects. Time-shared performance of monitoring, tracking, mental arithmetic, and problem solving tasks was measured by the Civil Aeromedical Institute (CAMI) Multiple Task Performance Battery (MTPB) in two 4-h test sessions, one in which smoking was permitted at 1/2-h intervals and a no-smoking session. Corollary physiological measurements involved urinary hormones (epinephrine, norepinephrine, and 17-ketogenic steroids), carboxyhemoglobin levels (COHb), and heart rate (HR).

Overall composite scores for MTPB performance revealed decrements during withdrawal which were statistically significant ($p < .01$) beginning at the third 1/2-h period of withdrawal sessions. The principal sources of the withdrawal effect were a significant ($p < .05$) decrement in tracking and a tendency toward longer reaction times in one monitoring task during withdrawal. These performance decrements were associated with significantly lower HR ($p < .001$) and lower ($p < .05$) ratings of attentiveness during withdrawal from smoking. These findings support a cautious approach to the prohibition of smoking on the flight deck for aircrew members.

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SOME EFFECTS OF SMOKING WITHDRAWAL ON COMPLEX PERFORMANCE AND PHYSIOLOGICAL RESPONSES

INTRODUCTION.

In 1976, the Federal Aviation Administration (FAA) was petitioned to prohibit all smoking on the flight deck during all commercial flight operations and to ban smoking by commercial flight crew members within an 8-h period before flights (15). In scientific evaluations of this petition, it was concluded that, although there are well demonstrated adverse effects on the health of smokers, carbon monoxide and nicotine at the levels of smoker intake have not been shown to produce adverse effects of practical significance on the performance of flight tasks in healthy pilots (4,14). Both reports, however, recognized the need for additional research on several issues including the potential adverse effects of short term withdrawal from smoking on the performance of pilots who are habitual smokers. Dille and Lindner (4) wrote "For some, withdrawal symptoms including tension, depression, irritability, difficulty in concentration, decreased heart rate, a fall in blood pressure, electroencephalographic changes, and impaired performance may occur and may more than offset any benefits to aviation safety that are expected from a ban on preflight and in-flight smoking." Although a number of experimental reports have addressed this issue, the need for additional research on the effects of smoking withdrawal on performance in aviation related tasks at an operational aircraft cabin altitude was recognized (4). The present experiment examined the effects of smoking withdrawal during a 4-h period on the complex (time-shared) performance of healthy habitual smokers in flight-related tasks at a simulated cabin altitude of 6,500 ft.

METHOD.

Subjects. Seventeen healthly paid volunteers who were all habitual smokers served as subjects. The nine female subjects ranged in age from 25 to 59 yrs with a mean of 40 yrs. The eight male subjects ranged in age from 23 to 59 yrs with a mean age of 39 yrs. All subjects had smoked at least one pack of cigarettes a day for the last 8 yrs. The mean duration of the smoking habit was 22 yrs.

After selection, subjects received four 3 1/2-h training sessions on the Civil Aeromedical Institute's (CAMI) Multiple Task Performance Battery (MTPB). After training, subjects underwent two 4-h experimental sessions held with 2 days between sessions. Figure 1 summarizes the experimental protocol for test sessions. Each experimental session consisted of six 30-min MTPB periods separated by 10-min "breaks." During the test session for the Smoking Condition, the subjects smoked one cigarette during the 10 min immediately prior to the first 1/2-h period and one cigarette during each 10-min break thereafter. During the test session for the No Smoking Condition, subjects were allowed to smoke one cigarette prior to the first MTPB period but did not smoke again for the entire 4-h session. Each subject completed preexperiment and postexperiment questionnaires consisting of subjective rating scales for attention, energy, strain, interest, irritability, and the state portion of the *State-Trait Anxiety Inventory* (STAI).

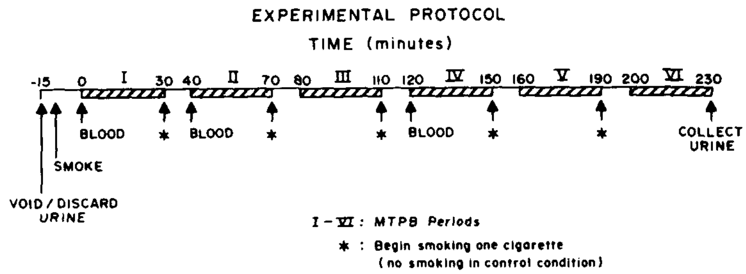

Figure 1. Experimental Protocol for test sessions.

Venous blood samples were drawn after each subject smoked prior to the first MTPB period. Additional blood samples were drawn after the first and third MTPB periods at the end of the 10-min break periods. The latter two blood samples were taken just after the subject smoked one cigarette in the Smoking Condition. All urine that formed during the 4-h test session was collected, acidified with HCl and frozen immediately. The blood sample was immediately analyzed for carboxyhemoglobin saturation; the instrument used was a Model 282 laboratory CO-Oximeter manufactured by Instrumentation Laboratories, Lexington, Massachusettes. Urine samples were later thawed and analyzed for epinephrine and norepinephrine by an adaptation of the method of Fiorica and Moses (3,5). In this adaptation, the catecholamines are isolated via alumina adsorption using a batch rather than a column technique.

Before each experiment, chest electrodes were attached and heart rate (HR) was continuously recorded by means of an electromagnetic tape recorder.

Multiple Task Performance Battery. The CAMI MTPB was used to measure time-shared performance in up to six component tasks simultaneously. The MTPB system is computerized; task presentation and data collection are automatic. The test panel displays and response controls are depicted in Figure 2. The system has been described elsewhere (2,10,11). A brief description follows:

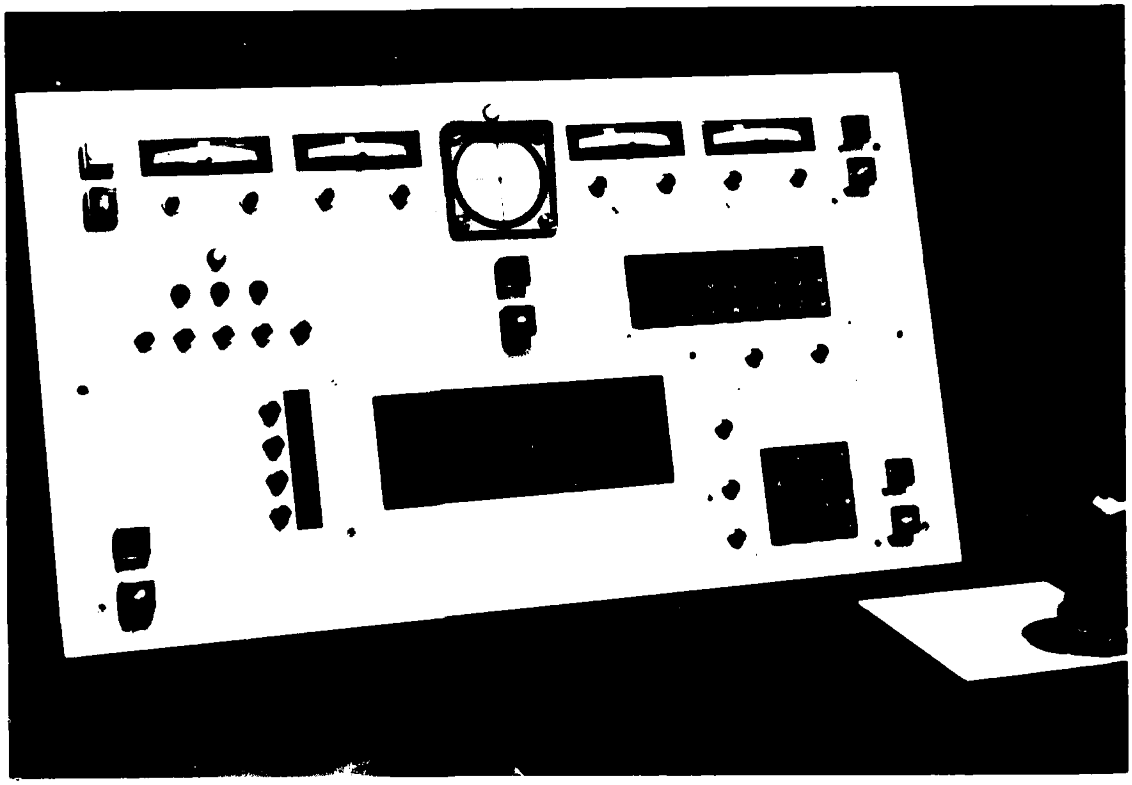

Figure 2. Multiple Task Performance Battery Console.

<u>Tasks 1 and 2: Monitoring of Red and Green Warning Lights</u>. This is a choice/reaction time task involving the monitoring of five green lights (normally on) and five red lights (normally off). The 10 lights were arranged in pairs of green and red. One pair is located in each corner of the test panel and a fifth is located in the center of the panel. The light lenses also serve as the pushbutton/switches. The subject was instructed to push the lens/switch whenever the light changed state. The measure of performance on these tasks is mean response latency recorded separately for red and green lights.

Task 3: Monitoring of Meters. This task involves monitoring four meters whose pointers move at random around the midpoint of the meter scale. The subject responds to a shift in the mean position of the pointer by pressing one of two buttons under the meter to report a left or right shift. The four meters are arranged across the top of the test panel. The performance measure is mean response latency.

Task 4: Mental Arithmetic. The subject is required to add two numbers and subtract a third number from the sum of the first two. All numbers contain two digits. All computations are performed mentally without writing down or recording intermediate stages of the solution. Answers are recorded by a 10-key response panel. The arithmetic task display is located in the lower center of the test panel with the keyboard to the right of the display. Performance measures are the mean response latency and percent correct answers.

Task 5: Two-Dimensional Compensatory Tracking (TRK). The tracking task display is an oscilloscope screen mounted in the top center of the subject's panel. The target on the screen is a dot of light about 1 mm in diameter. A varying amplitude disturbance is imparted to the target in each dimension; the subject attempts to counteract the disturbance, keeping the dot at center screen, by moving a control stick with his right hand. Performance is measured in arbitrary units (volts) by analog circuitry in terms of mean integrated absolute error and mean error squared for both horizontal and vertical dimensions. These data are converted to measures of absolute vector error and root-mean-square (RMS) vector error, which are the performance measures.

Task 6: Problem Solving (PS). Each test panel is equipped with five response buttons, a "task active" light, and three "feedback" lights, all located at the left center of the test panel. The problem is to discover the correct sequence in which to press the five response buttons. Each button appears only once in a given trial. Subjects are instructed to use a trial-and-error procedure and a left-to-right search pattern. An amber feedback light is illuminated every time a button is pressed to show that the response is acknowledged by the system. Pressing buttons in incorrect order causes a red light to turn on and stay on until the next correct response is made. Pushing all five buttons in correct order causes a blue light to turn on. When a problem is solved, a lapse of 15 s occurs, following which the same problem is presented a second time. The subject is expected to reenter the previous solution from memory on the second, or confirmation presentation. After another 15 s a new problem is presented. Performance measures for this task are: (i) mean response latencies for the first solution and the confirmation stages; (ii) the percentage of nonredundant and correct responses made during the first solution and confirmation stages, respectively; and (iii) mean time per problem for both solution and confirmation stages.

MTPB Procedure. A basic 30-min schedule of the six MTPB tasks was used. This 30-min period was divided into three 10-min intervals. Tasks 1, 2, and 3 were given throughout the schedule. In the first 10-min interval, Task 5 was also active. In the second interval of each period, Tasks 5 and 6 were also active. In the third interval, Tasks 4, 5, and 6 were also active. The task schedules for the three intervals were named the low, medium, and high workload conditions, respectively, and were always presented in the same order in each period. The four practice sessions were each of six 30-min periods. The experimental sessions also contained six 30-min periods.

Performance was assessed in terms of raw and composite scores for each task. Composite scores summarized all measures of performance for the particular task. An overall composite score (all tasks) was also obtained. Individual composite scores were calculated as follows: for each measure of performance on a task, the scores of an individual subject were converted to standard scores with a mean of 500 and a standard deviation of 100. The task composite score for each subject and experimental treatment was the mean of standard scores on each measure of performance for that task. The sign of scores was changed, when necessary, so that higher standard scores always indicated higher performance and lower scores, lower performance. An overall composite score was also calculated for each subject and treatment by averaging the composite scores for different tasks so that each task made an equal contribution to the variance. Analyses of task and overall composite scores were made because they: (i) simplify the evaluation of a large amount of data; (ii) have been found to be more sensitive to the effects of experimental conditions than the individual measurements of performance; and (iii) have higher reliability than raw score data on individual performance measures (2,11).

RESULTS.

Physiological and Biochemical Responses. Carboxyhemoglobin levels are shown in Table 1 and were generally lower in the No Smoking Condition than in the Smoking Condition; however, the difference between conditions was significant ($p < .001$) for those measurements taken 120 min after the experiment began. Data for the effects of experimental conditions on heart rate, urine production, and urinary excretion rate for catecholamines are summarized in Table 2. There were no statistically significant effects of withdrawal for excretion rates of urinary hormones or urine volume. Heart rate was significantly ($p < .001$) higher when the subjects smoked.

Table 1. Mean and Standard Deviation of Carboxyhemoglobin Level %HbCO as a Function of Time the Sample was Taken and Smoking Condition

Time		Smoking	No Smoking
0 min (Before Period 1)	Mean	7.69	6.04
	S.D.	3.44	2.48
40 min (After Period 1)	Mean	7.58	5.82
	S.D.	2.99	2.07
120 min (After Period 3)	Mean	8.02	4.26*
	S.D.	2.97	2.22

*$p < .001$

Complex Performance. Overall composite MTPB score data are shown in Figure 3 and Table 3. All performance data were analyzed by analysis of variance. Performance decreased during abstinence relative to the smoking condition. This decrement became apparent during the third 1/2-h of MTPB performance and continued through the remainder of the experimental session. Both the main effect of smoking ($p < .01$) and the interaction of smoking with time period ($p < .05$) were statistically significant. Individual comparisons of means shown in Figure 3 indicated a significantly lower level of performance ($p < .05$) in the third, fourth, and sixth periods of the smoking withdrawal session.

Composite score means and standard deviations for the main effects of smoking and test period are summarized in Table 4 for each component task. Tracking was the only MTPB component to exhibit a statistically significant main effect of smoking withdrawal, although there is also a tendency for performance in the monitoring of red lights to decrease during withdrawal over the first three 1/2-h periods of MTPB testing. There is also a tendency for performance to increase with time in the Smoking Condition in the latter task. In the case of tracking performance, the adverse effect of smoking withdrawal was independent of a trend toward decreasing performance with time, which occurred in both Smoking and No Smoking Conditions. The steady decline in tracking performance during the Smoking Condition was, however, apparently offset by increases in performance of other components of the MTPB as shown in the composite score data for the Smoking Condition in Figure 3. A tendency for increase in performance with time during MTPB testing in the Smoking Condition appears in the case of both red lights and arithmetic tasks. The main effect of periods was significant ($p < .01$) only in the arithmetic task. No significant interaction of smoking with time period occurred in composite score data for individual tasks.

Table 2. Means and Standard Deviations of Heart Rate, Urine Production Rate, and Urinary Excretion Rate of Catecholamines as a Function of Smoking Condition

HEART RATE (bpm)

	Smoking	No Smoking
Mean	80.5	73.4*
S.D.	11.1	9.0

URINE VOLUME (mL/h)

	Smoking	No Smoking
Mean	339	312
S.D.	204	245

EPINEPHRINE (ng/h)

	Smoking	No Smoking
Mean	1000	900
S.D.	768	470

NOREPINEPHRINE (ng/h)

	Smoking	No Smoking
Mean	2561	2532
S.D.	1034	1222

*$p < .001$

Table 3. Overall Composite Score Means, and Standard Deviations as a Function of Smoking Condition and Time Period

		Periods					
		1	2	3	4	5	6
Smoking	Mean	504	505	530	501	501	521
	S.D.	40	37	31	33	31	37
No Smoking	Mean	507	497	493	473	491	471
	S.D.	31	39	31	28	68	37
Difference (S-NS)		-3	8	37	28	10	50

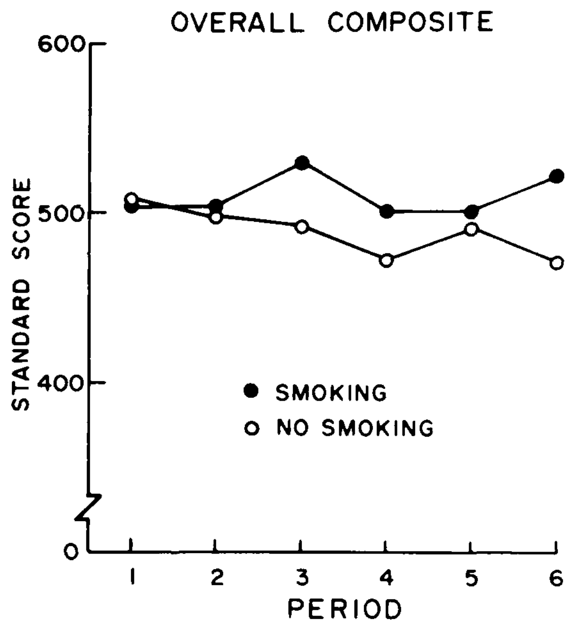

Figure 3. Overall MTPB composite scores summarizing performance on all tasks as a function of smoking condition and time period.

Table 4. Composite Score Means and Standard Deviations as a Function of Smoking Condition and Time Period

		Conditions		Periods					
		Smoking	No Smoking	1	2	3	4	5	6
Green Lights	Mean	498	502	504	512	509	488	503	485
	SD	101	101	107	84	109	101	102	103
Red Lights	Mean	514	486	515	483	509	488	497	507
	SD	92	103	80	117	84	98	121	86
Meters	Mean	508	492	500	496	503	495	486	520
	SD	94	103	106	102	94	104	106	77
Tracking	Mean	535	465*	576	526	519	477	475	427**
	SD	79	72	90	53	83	60	82	84
Problem Solving	Mean	502	498	495	485	523	488	506	502
	SD	103	60	64	56	47	55	68	50
Arithmetic	Mean	507	491	445	505	507	487	511	540**
	SD	71	79	96	74	69	76	74	62

* $p < .05$
** $p < .01$

Raw Score Data. Raw score data (means and standard deviations) for individual performance measures in each task are shown in Table 5 as a function of the main effects of smoking, workload, and test period. These data show slight decrements during withdrawal in 9 of the 13 performance indices, with statistically significant ($p < .01$) performance decrements in withdrawal occurring only in the case of absolute and RMS tracking errors.

The workload factor was varied in all tasks but mental arithmetic. Increasing workload consistently caused a decrease in performance in all tasks. The effect of workload was statistically significant at the $p < .01$ level in indices of tracking performance and problem solving performance, and significant at the $p < .05$ level in the monitoring of red lights and meters. Workload had no statistically significant interaction with smoking or periods.

The effect of time period was statistically significant in tracking performance, problem solving and mental arithmetic. Both indices of tracking performance showed a significant ($p < .01$) decline in performance

Table 5. The Main Effects of Smoking, Time Period, and Workload in the Individual Performance Measures (Raw Scores) for All Tasks

		Smoking		Period						Workload		
		Yes	No	1	2	3	4	5	6	Low	Medium	High
GREEN LIGHTS Response Latency (ms)	Mean	4620	4579	4547	4484	4374	4809	4558	4823	3386	4571	5840
	S.D.	2656	2736	2747	2470	2586	2858	2516	3000	1993	2752	2696
RED LIGHTS Response Latency (ms)	Mean	2342	2929	2433	2721	2566	2664	2843	2585	1945	2680	3280*
	S.D.	1179	2019	1331	1651	1494	1628	2005	1483	941	1768	2087
METERS Response Latency	Mean	20679	21035	20866	20686	20846	21028	21486	20229	11951	16746	33874*
	S.D.	10602	9980	9224	9800	11540	11029	11187	9951	5053	6862	18960
TRACKING Absolute Error	Mean	557.4	591.8*	535.2	562.6	564.9	583.2	588.2	613.7**	337.7	639.1	747.1**
	S.D.	157.2	153.7	158.4	154.2	158.5	150.7	146.9	164.2	135.0	128.1	153.3
RMS Error	Mean	88.6	93.0**	86.4	89.0	89.8	91.9	92.6	95.2**	59.5	100.0	112.9**
	S.D.	22.5	22.5	22.9	22.1	23.2	22.5	21.9	22.7	20.4	24.0	23.2
PROBLEM SOLVING SOLUTION Time Per Response (ms)	Mean	1030	1024	1101	1061	1002	985	1013	1000**	--	868	1186**
	S.D.	226	200	227	206	236	195	220	196	--	150	276
Percent Nonredundant Responses	Mean	95.3	94.8	95.2	95.1	95.5	95.2	95.0	94.4	--	95.9	94.2**
	S.D.	4.2	4.7	4.3	4.6	5.5	4.5	4.1	4.2	--	3.5	5.4
Time Per Problem	Mean	14886	14996	15211	15147	13964	15614	14914	14292*	--	12684	17197**
	S.D.	3616	3087	3599	3378	3492	3448	3303	2890	--	2310	4393
PROBLEM SOLVING CONFIRMATION Time Per Response (ms)	Mean	1081	1070	1107	1114	1086	1056	1044	1046	--	868	1283**
	S.D.	262	186	329	226	291	212	246	250	--	199	259
Percent Correct	Mean	82.2	82.1	83.7	82.4	83.2	80.2	81.1	82.2**	-	88.0	76.3**
	S.D.	10.1	10.8	9.4	10.5	11.5	11.5	10.6	10.1	--	10.0	11.0
Time Per Problem (ms)	Mean	9188	9002	8758	9166	9438	9586	8686	8935	--	6128	12061
	S.D.	3865	4018	4167	3845	4731	3849	3286	3772	--	2714	3941
MENTAL ARITHMETIC Time Per Problem (ms)	Mean	14009	14575	15309	14265	14223	14238	14197	13520*	--	--	14292
	S.D.	3077	3097	3291	3274	2778	3130	3236	2815	--	--	3087
Percent Correct	Mean	82.0	82.3	77.0	84.2	83.6	80.8	82.9	94.5*	--	--	82.2
	S.D.	16.4	15.5	15.8	16.1	16.6	16.3	17.3	13.6	--	--	16.0

* $p < .05$
** $p < .01$

over time, while both indices of mental arithmetic performance showed a significant ($p < .05$) increase in performance over the course of an experimental session. The significant effect of periods in problem solving seems to reflect only a temporary increase in performance during the third 1/2-h period of a session. These trends can be inferred from Figure 4 which in turn shows the corresponding composite score data for these three tasks. In no case was there a significant interaction of the smoking factor with periods.

Subjective Rating Scale Data. Ratings of attentiveness, shown in Table 6, were significantly ($p < .05$) higher when subjects smoked. There was a slight but nonsignificant decline in attentiveness over time (before experimental testing vs. after testing) in both Smoking and No Smoking Conditions. Ratings indicated significantly ($p < .05$) higher levels of tiredness, tension, boredom, and irritation at the end of the experiment than before, but no effects of smoking withdrawal were found with these variables. Arousal, as measured by the State portion of the STAI, was not significantly affected by either smoking or time of testing, but smoking tended to increase arousal, and withdrawal to decrease arousal, over the course of the session.

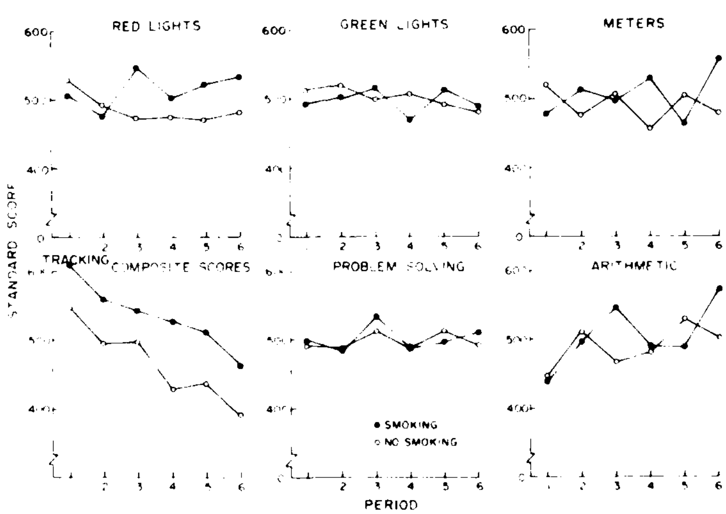

Figure 4. Composite scores for individual tasks of the MTPB as a function of smoking condition and time period.

Table 6. The Effects of Smoking and Time of Measurement on Subjective Rating Scale Responses

Rating Scale		Smoking		No Smoking	
		Before	After	Before	After
Attentiveness	Mean	6.35	[illegible].82	5.71	5.00
	S.D.	2.15	1.91	1.96	1.12
Tiredness	Mean	4.76	5.63	4.24	6.18
	S.D.	1.68	1.71	1.60	1.19
Tenseness	Mean	3.59	4.41	3.82	4.59
	S.D.	1.66	1.80	1.33	1.46
Boredom	Mean	2.76	3.88	2.76	4.41
	S.D.	1.82	2.23	1.99	1.70
Irritation	Mean	1.41	2.29	1.35	2.58
	S.D.	1.06	2.23	1.00	1.80
STAI-X1	Mean	31.47	33.35	35.12	31.12
(Arousal)	S.D.	8.98	11.85	8.67	9.80

DISCUSSION.

In the present experiment in which complex performance was measured at a simulated operational cabin altitude of 6,500 ft, there was a significant adverse effect of smoking withdrawal. When smoking was permitted the overall index of performance was maintained at the initial level or higher over the 4-h of testing. When smoking was prohibited, however, performance declined with time. That effect was largely a result of a decrement in tracking performance, a psychomotor function important to flying. Vigilance performance regarding red lights also showed a similar trend, but the effects of smoking withdrawal were not statistically significant in that case. Decrements in performance due to smoking withdrawal were associated with subjective reports of decreased attentiveness, both prior to and after the experiment. The decrement in attentiveness ratings prior to the experiment suggests an effect of anticipation of withdrawal on the cognitive state of subjects, but no corresponding decrement in overall performance was found in the first 1/2-h test period. Tracking performance in the first 1/2 h was, however, lower in the No Smoking condition than in the Smoking Condition. This suggests that anticipation of withdrawal may have restructured relative task priorities to the benefit of other tasks in the first 1/2 h of the withdrawal condition. Trends in tracking and arithmetic task performance over time also suggest changes in task priorities. The decline in tracking performance with time was balanced to some extent by an increase in performance of arithmetic. Both trends were independent of the effect of smoking. This suggests a reciprocal change in priorities or attention to those two tasks over time. This apparent change in priorities or allocation of attention over time is unexplained but may be related to fatigue buildup during the test session. A fatigue buildup is supported by the significant increases in subjective ratings of tiredness, tenseness, boredom, and irritation that occurred in both Smoking and No Smoking Conditions.

Increasing workload was consistently associated with decreasing performance in all tasks that occurred under varying workload conditions. In no case, however, did workload have a significant interaction with smoking treatment.

The higher HR and higher attentiveness scores obtained when the subjects smoked are consistent with the performance data and suggest that decreased arousal in the absence of smoking may be the mechanism causing the detrimental effects of smoking withdrawal in habitual smokers.

Although there was some disparity among subjects with respect to the yields of tar and nicotine of the cigarettes they usually smoked, there were no apparent effects of cigarette type on levels of COHb in the present study. This lack of correlation of yield with COHb saturation, and with blood nicotine levels, is well known (16). Although the effects of low levels of carbon monoxide on MTPB performance have not yet been studied, it might have been expected that lowered carboxyhemoglobin levels would contribute toward enhanced performance. We conclude that any positive effects that might have been obtained from a decreased carboxyhemoglobin level were offset by the negative effects of withdrawal.

Our findings of decrements in complex task performance at an operational aircraft cabin altitude, and tracking performance in particular, corroborate the findings of several previous experiments conducted at ground level. Heimstra, Bancroft, and DeKock (8) compared the performance of smokers, smokers deprived, and nonsmokers in a complex simulated automobile driving task involving tracking, reaction time, and vigilance components. Although there were no significant differences between the performance of nondeprived smokers and nonsmokers, smokers who were deprived had significantly inferior tracking and vigilance performance. A second experiment, by Heimstra, Fallesen, Kinsley and Warner (9), studied the effect of smoking withdrawal on complex performance using tracking, reaction time, vigilance, and mental arithmetic as component tasks. Tracking performance was significantly lower in the smoking deprivation condition. Performance in other tasks was not affected by withdrawal, as was the case in the present study.

Two other studies involving tracking in dual task situations have also shown tracking to be sensitive to smoking withdrawal. In a study cited by Heimstra (7), Bancroft, Heimstra, and Warner (1) examined simultaneous performance in pursuit-rotor tracking and reaction time tasks in nonsmokers, smokers-deprived, and smoker groups in a 3-h test session. Under high and low tracking difficulty, tracking performance was significantly lower in the smoker-deprived group, and in the low tracking difficulty condition reaction times were also slower. Warburton (20) cited a study of Tarriere and Hartman (18) in which smokers performed simultaneously in a central visual guiding task and a peripheral visual search task under smoking and smoking withdrawal conditions. Tracking (guiding) and search performance were lower during withdrawal.

At least five complex performance studies have, therefore, shown significant adverse effects of smoking withdrawal on the tracking component. There is also additional evidence that short-term withdrawal from smoking can produce decrements in vigilance (6,13,19,21), choice reaction time (13,17), and selective attention (12,21), in single task situations.

The present findings add to the body of evidence demonstrating important adverse effects of short-term smoking withdrawal on performance at a simulated operational air carrier altitude. These findings support the previous conclusion (4,9,14) that when considering the issue of restricting smoking in various work situations, including the flight decks of aircraft, the issue of negative effects of smoking deprivation on performance must be considered. Our results support a cautious approach to the prohibition of smoking for aircrew members. In light of the possibility that pilots who are habitual smokers may not perform well during withdrawal we recommend, as did Dille and Lindner (4), consideration of smoking cessation programs and other approaches milder than complete prohibiton of smoking during flight in aircraft.

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